



# **The Evolution of Subtropical Stratocumulus cloud properties from multiple satellite sensors using a new Lagrangian approach**

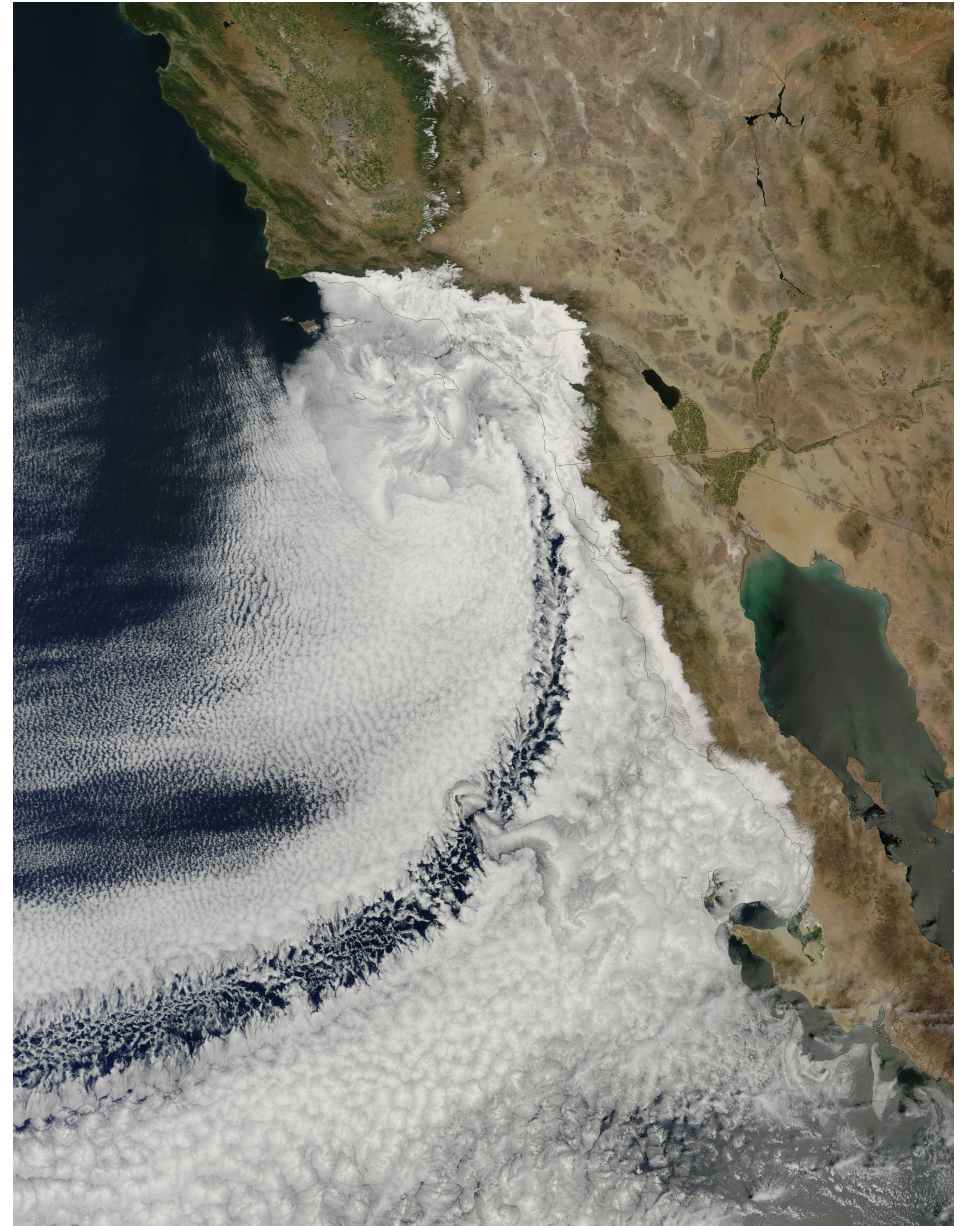
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**University of Washington  
2015**



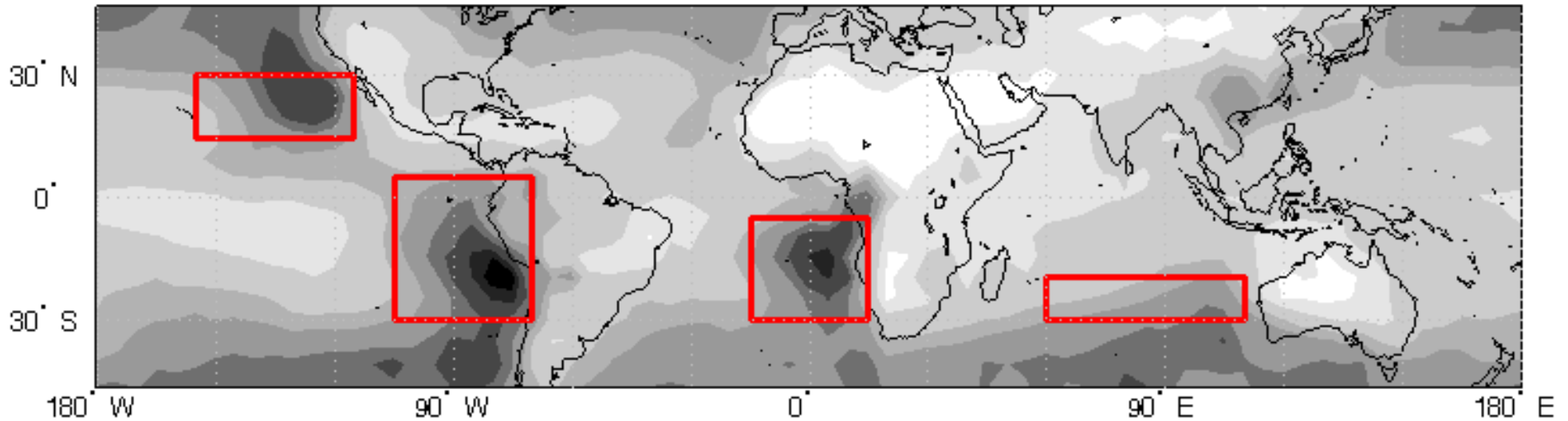
# The role of Sc decks in the climate

- Form in stable environments on large and small scales
  - In stable regions around midlatitude cyclones
  - Continent-sized cloud decks in the subtropics
- Act to cool the climate
  - Reflect an enormous amount of sunlight
  - Radiate LW similar to the surface



MODIS image courtesy Jeff Schmaltz

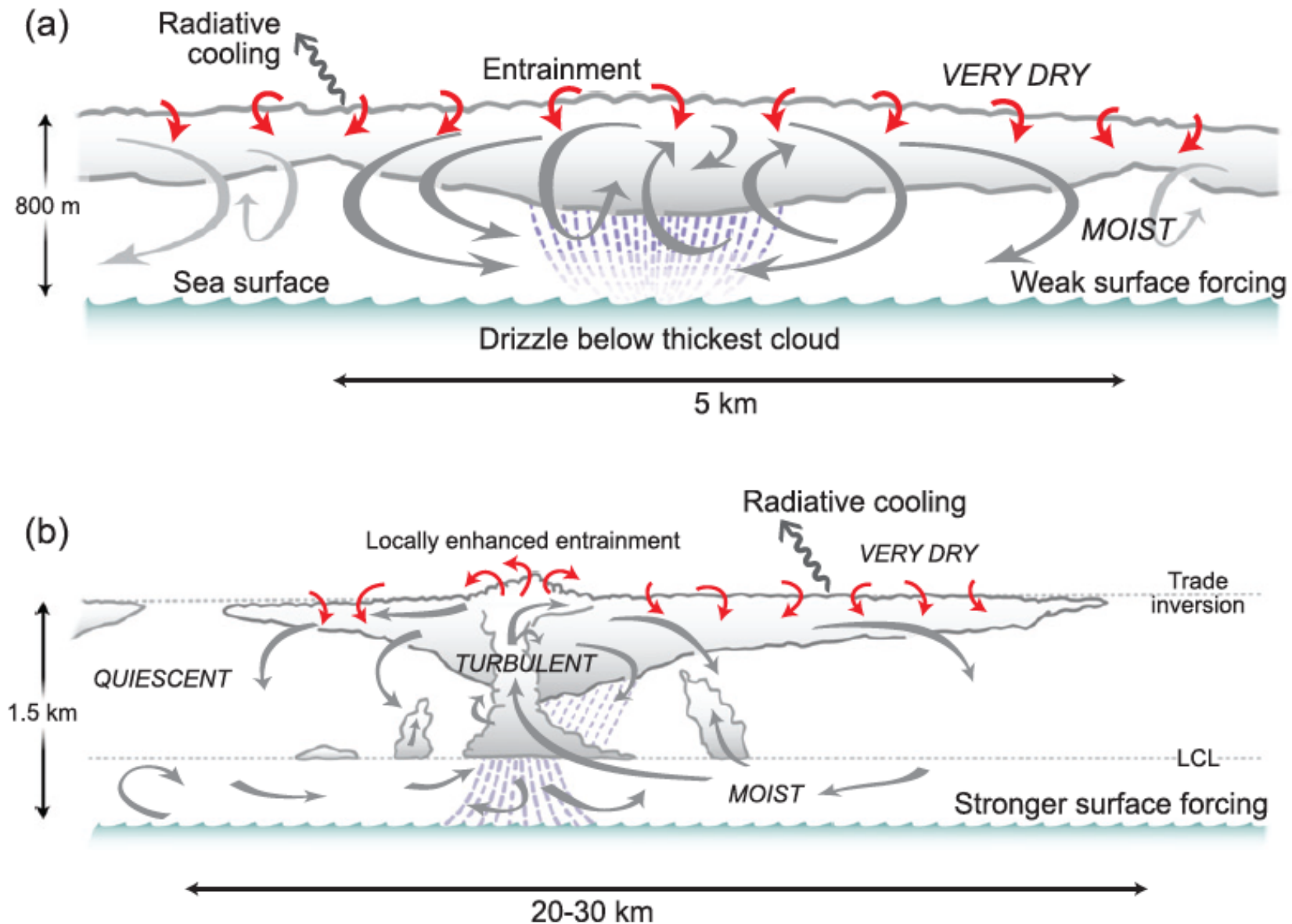
# Sc climatology from surface obs



Hahn & Warren Cloud Atlas: [www.atmos.washington.edu/CloudMap](http://www.atmos.washington.edu/CloudMap)

- Study Sc in eastern sub-tropical ocean basins, in regions of subsidence, offshore flow, and cool SST
- Looking for maxima near continents and declining Sc gradient offshore

# Shallow vs Deep Boundary Layers





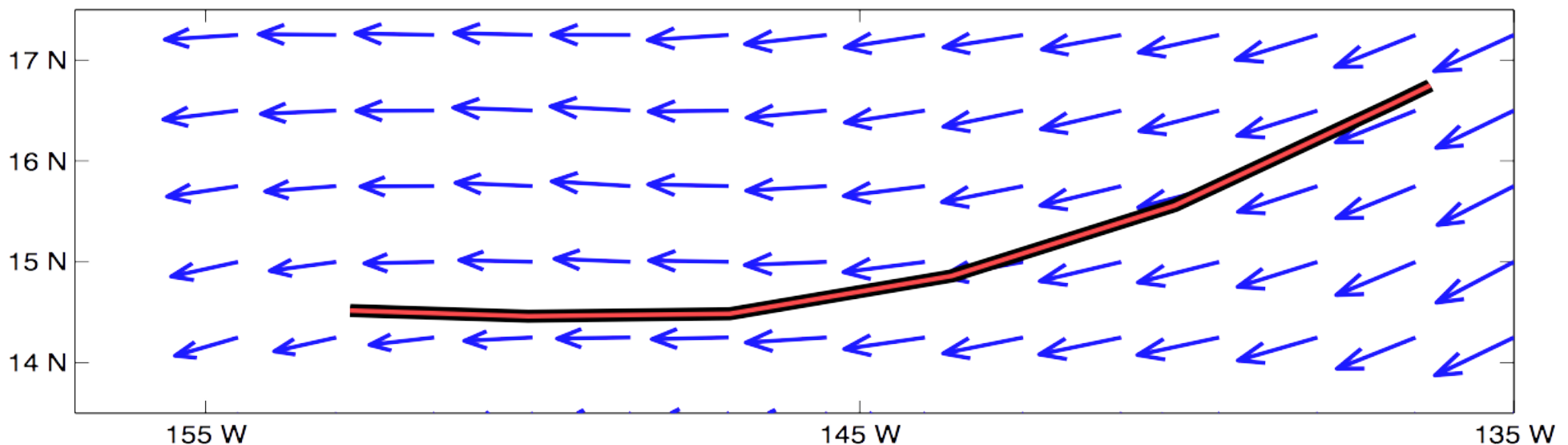
# Uncertainties concerning Sc breakup

- Many factors may contribute to Sc breakup over the remote ocean
  - Precipitation stabilizing the boundary layer
    - Condensation at cloud level, evaporation below
    - Removing CCN, encouraging precip, positive feedback
  - Weakening divergence offshore
  - Warming SSTs weakening the inversion
    - Boundary layer deepens, Sc layer decouples from surface
- Most of these things are correlated with one-another



# 24-hour Lagrangian Study

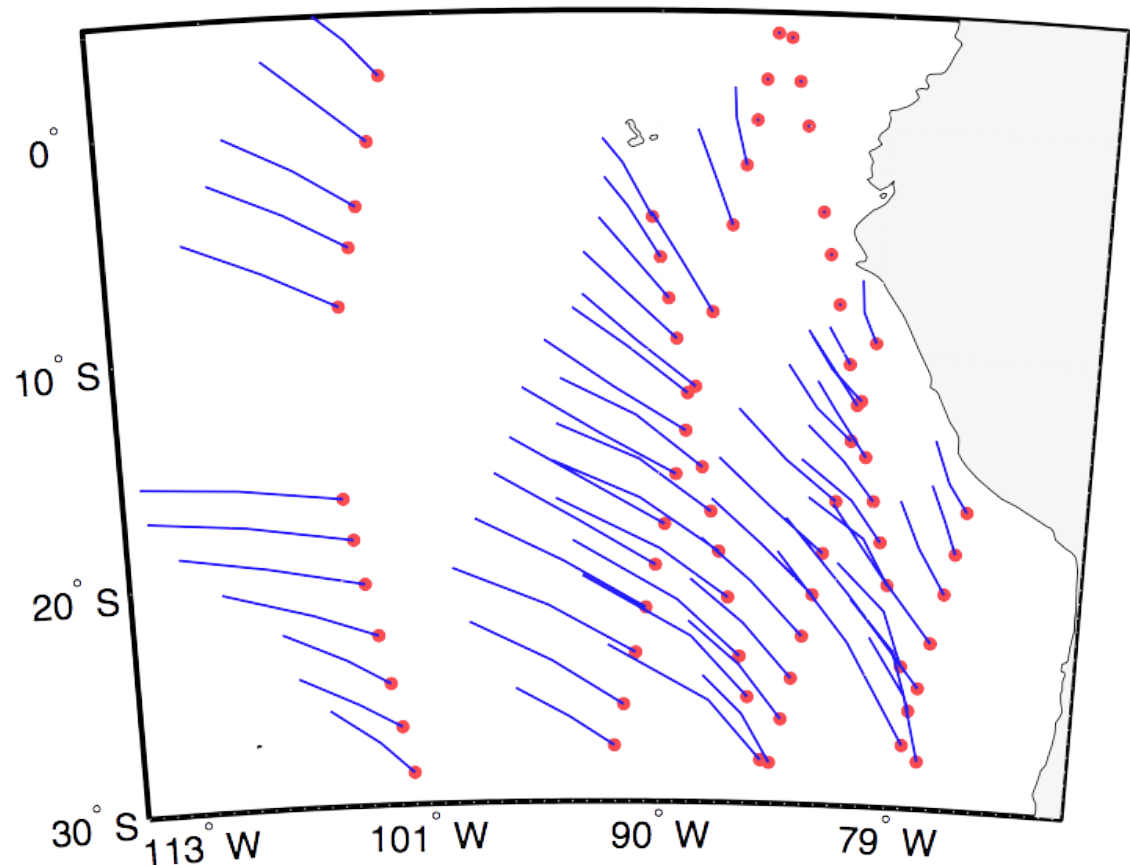
- Compute 24-hour trajectories from reanalysis data
  - ERA-Interim reanalysis U and V fields,  $0.75^\circ$  at 925 mb
  - For years 2007 & 2008 only for now





# 24-hour Lagrangian Study

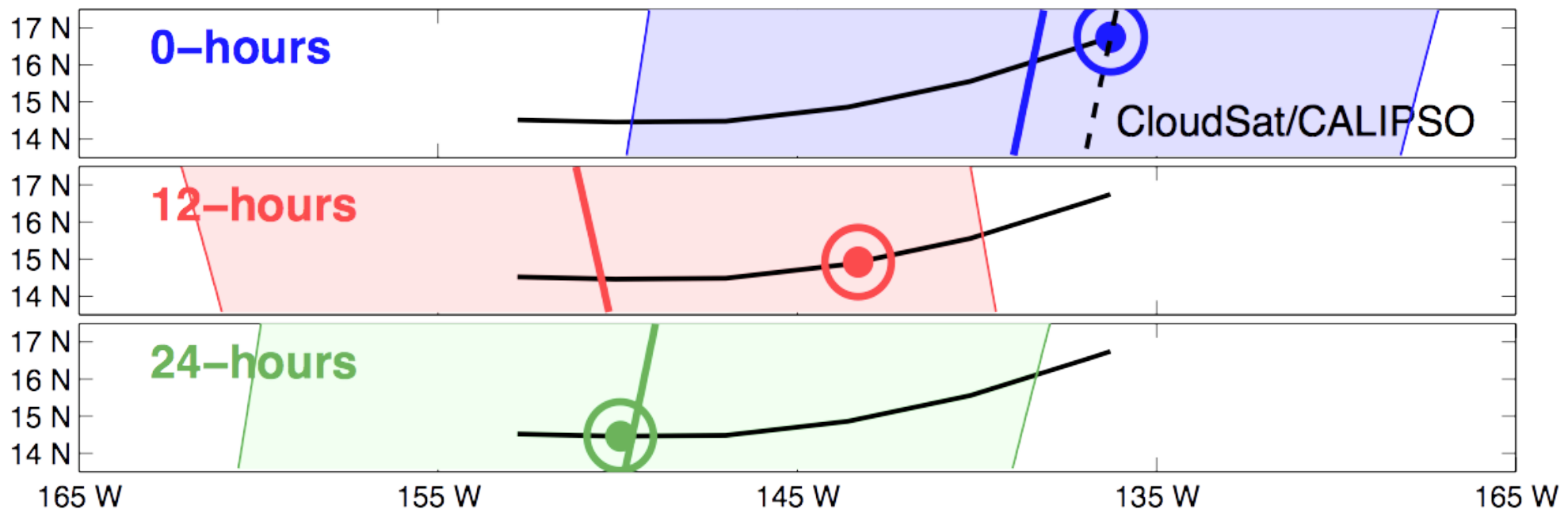
- Start at randomly chosen points along A-Train swath, at least 200 km apart, Day and Night,
  - Over 60,000 individual trajectories
  - Only study trajectories moving east-to-west





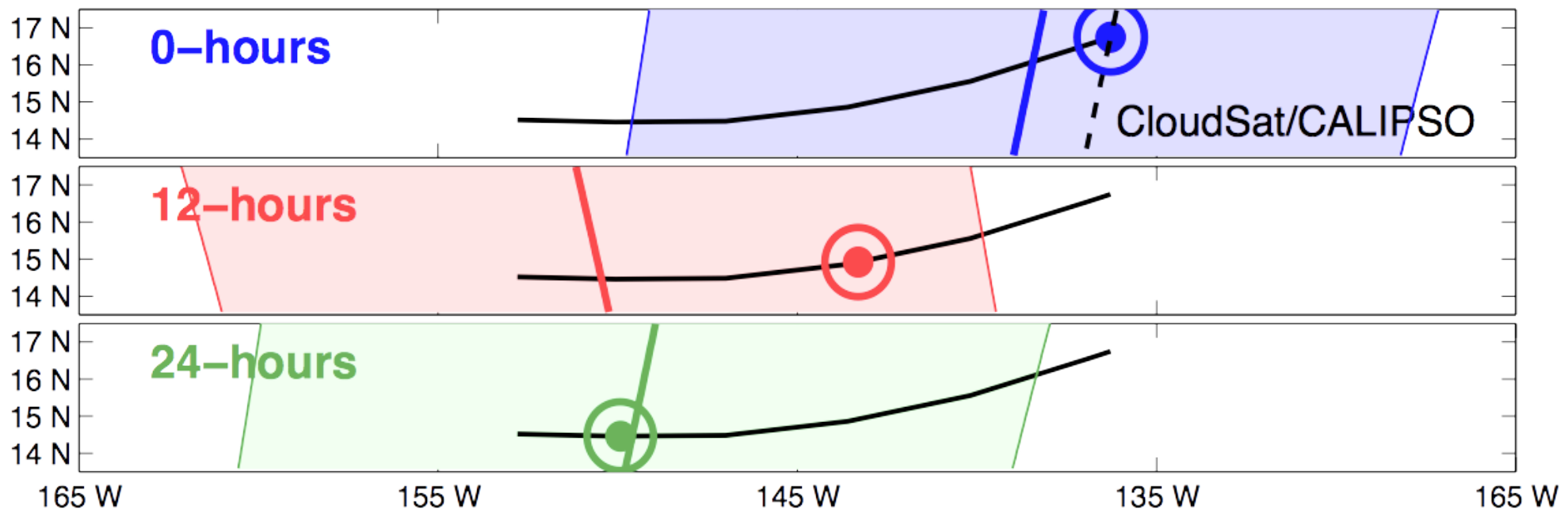
# 24-hour Lagrangian Study

- Look at the A-train sounding at the first point
  - Sample Precip using CloudSat 'Rain Profile' product
    - Determines whether precipitation reaches the surface
  - A sample with any precip is considered 'precipitating'



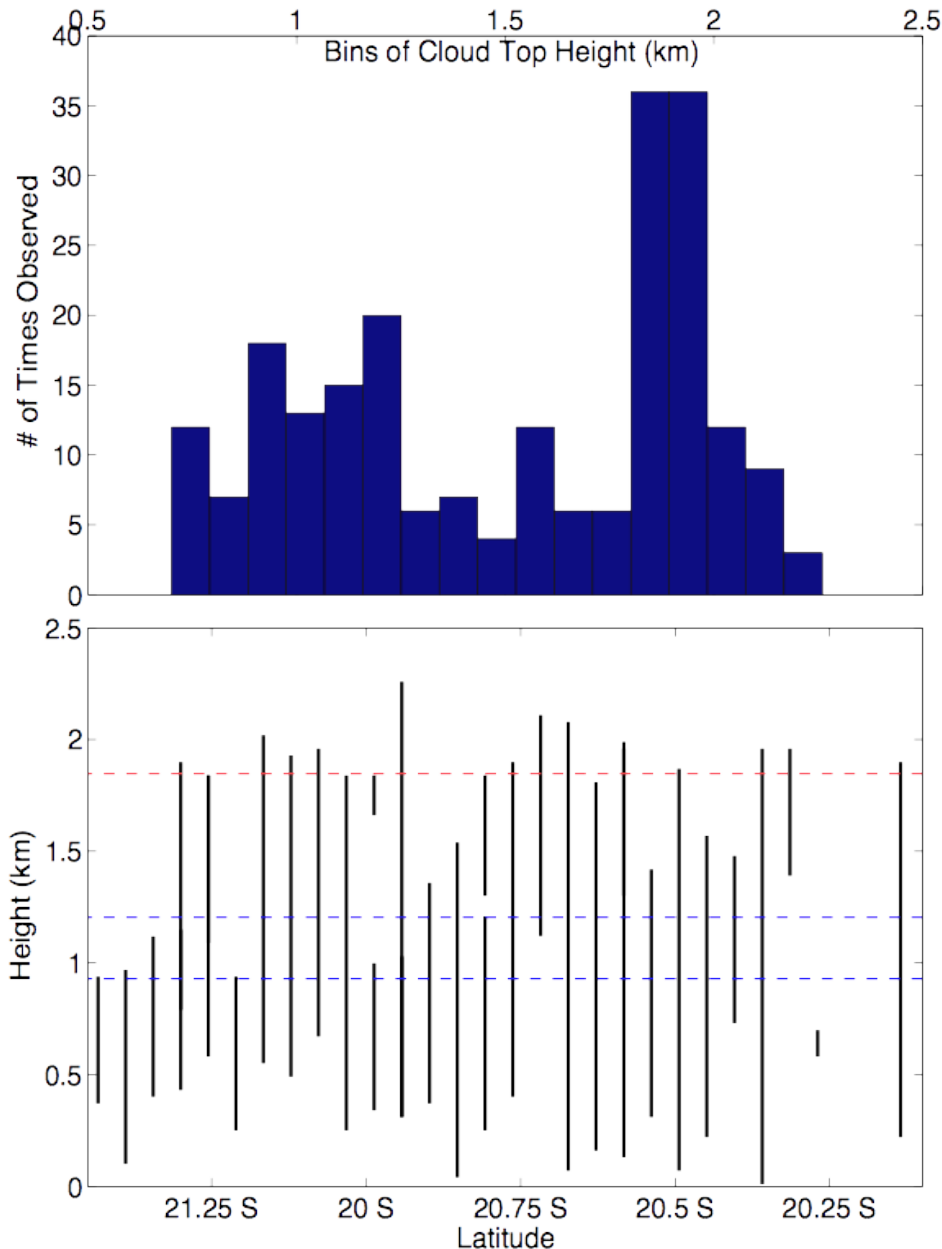
# 24-hour Lagrangian Study

- Use CALIPSO Vertical feature mask for boundary layer depth
  - Look at the lowest 3 km of the atmosphere
  - Assign a boundary layer depth using cloud-top returns





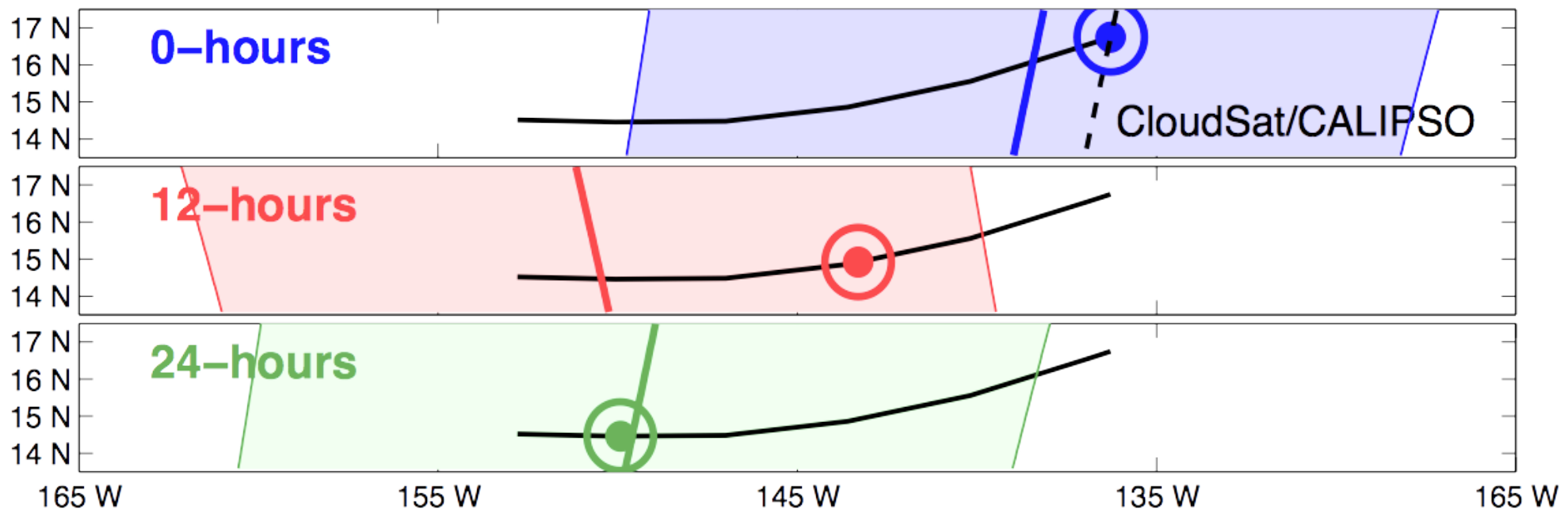
# CALIPSO Cloud Top Height



- Cloud top is not always obvious
  - Use histogram to find peaks in the frequency distribution of cloud tops below 3km
  - Peaks in the distribution are considered relevant if they are at least 40% as high as the highest peak
  - Choose the highest altitude relevant peak

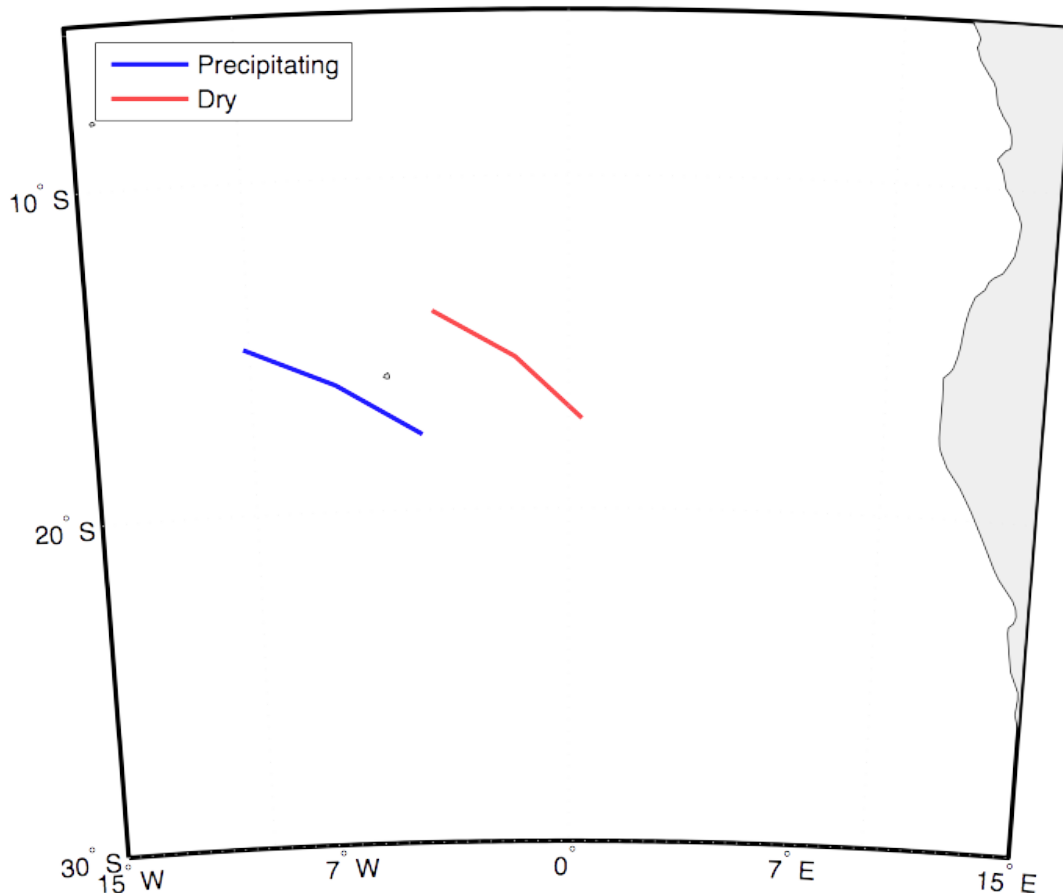
# 24-hour Lagrangian Study

- Use MODIS at **0**, **12**, and **24** hours
  - MODIS cloud mask day or night for 100 km radius
  - Level 3 data on a 1x1 lat-lon grid
  - Look at Delta Cloud Cover Anomaly in time ( $\Delta CCA$ )





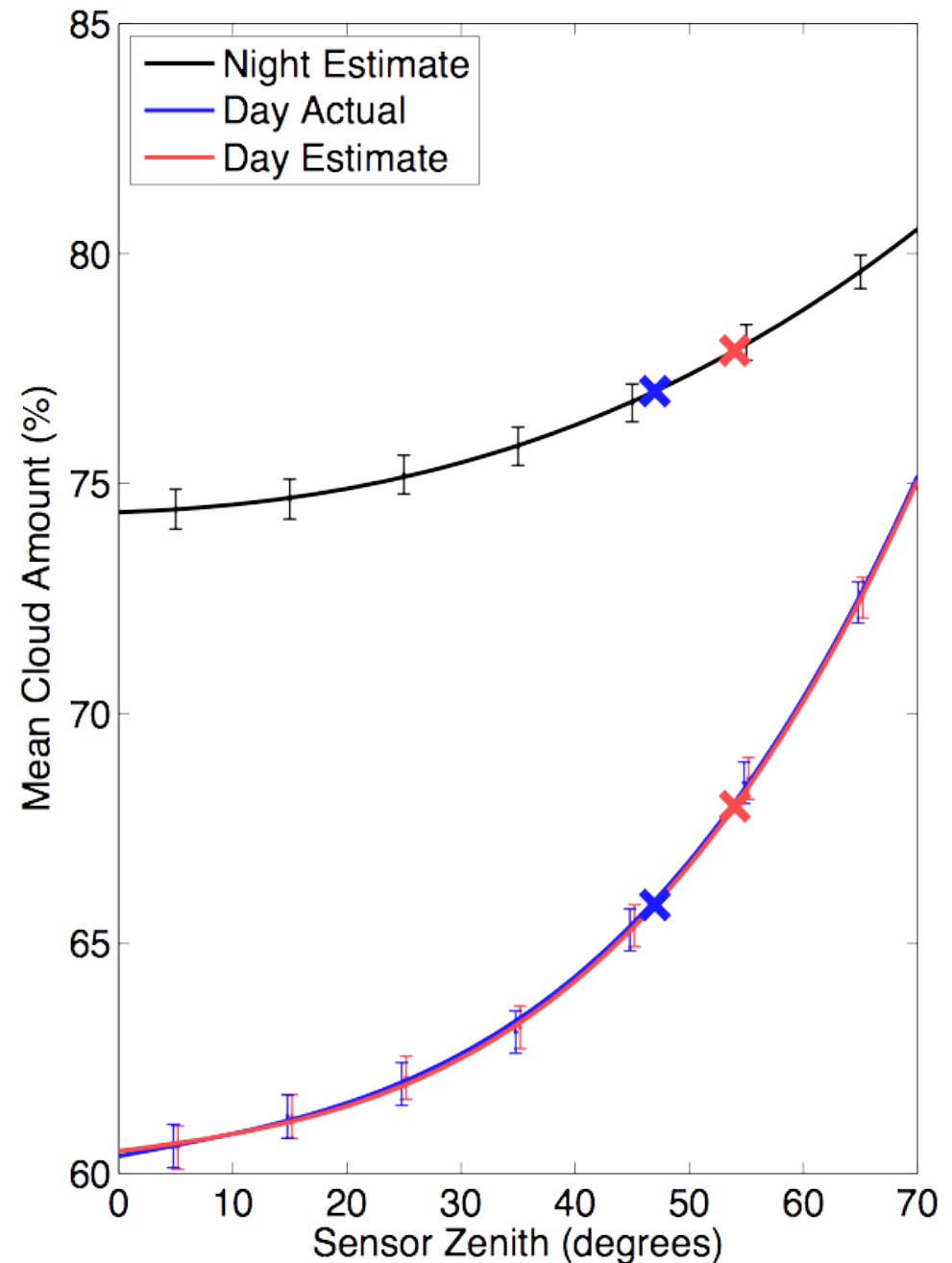
# Precipitating versus dry trajectories



- Dry and precipitating trajectories should not be directly compared
  - Mean locations and distance travelled of dry and precipitating trajectories are different
  - Precip trajectories tend to go farther, and cover more CC gradient offshore
- We use seasonal cloud anomalies instead of actual amounts

# MODIS Zenith Angle Bias

- MODIS senses more clouds at the edge of the swath due to:
  - Thin clouds appearing more opaque at high angles
  - Vertically developed clouds filling up more pixel
- Estimate day and night bias, and represent them as a polynomial, subtract from data



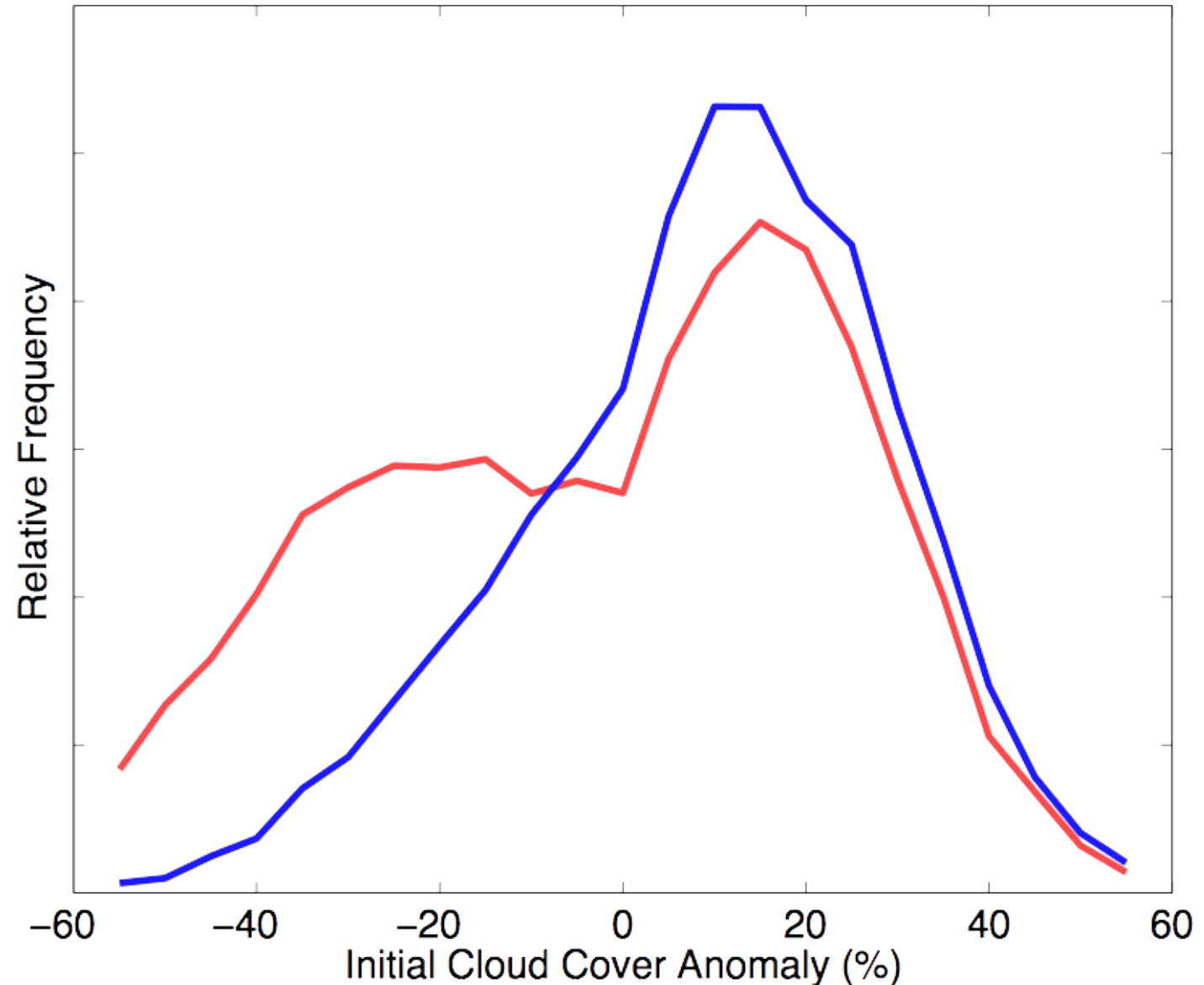


# Biases in a Lagrangian study

- Most significant: A bias due to the differing distributions of initial Cloud Cover Anomalies (CCA) between different groupings of trajectories
- e.g. Clouds are necessary for precipitation to occur, therefore when grouping trajectories by precipitation we must consider that:
  - Precipitating trajectories must start off with some cloud cover (usually lots of clouds)
  - Dry trajectories can start cloud-free

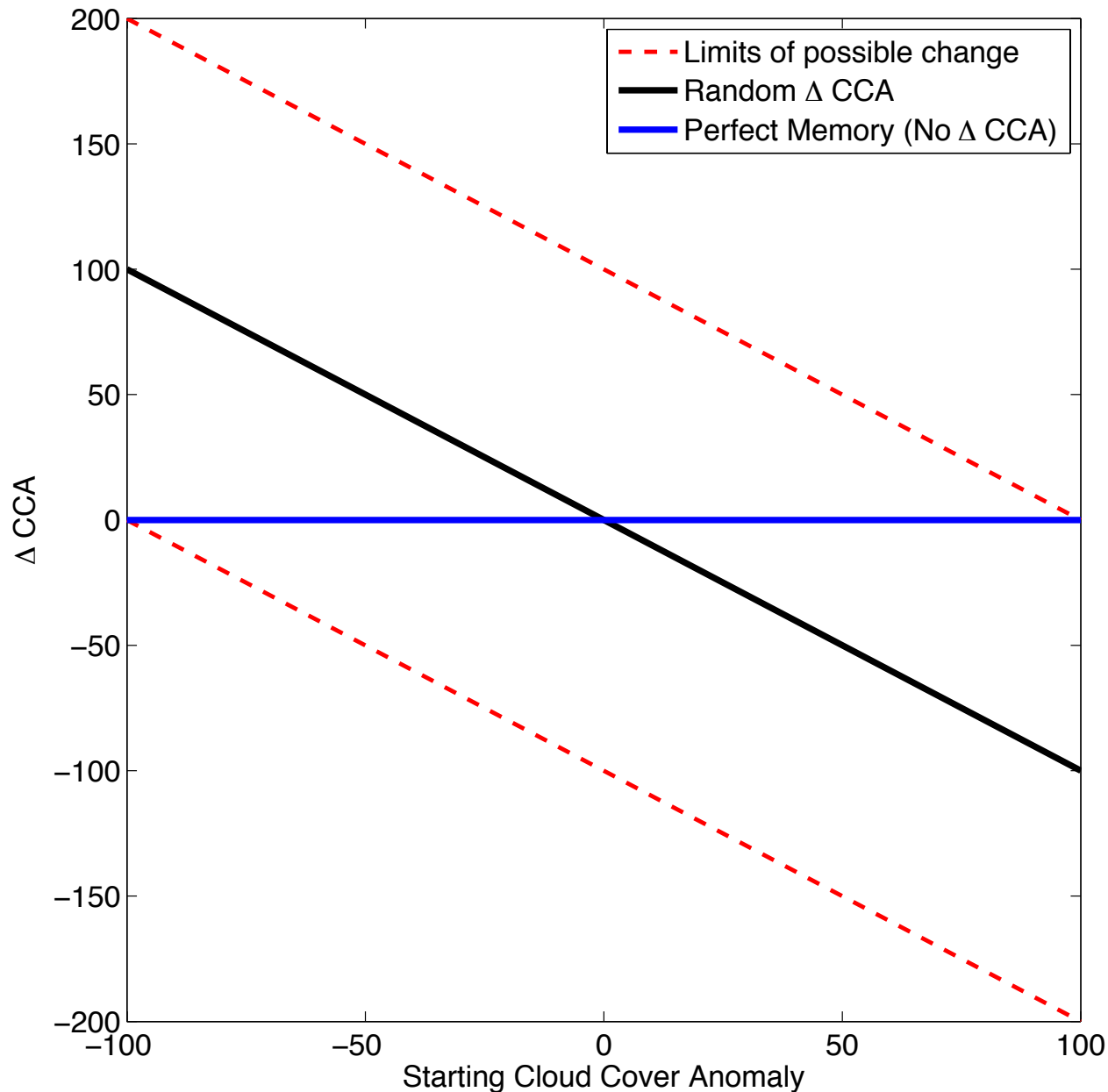
# Biases in a Lagrangian study

- More **positive** **precipitating** initial cloud cover anomalies (CCA)
- More **negative** **dry** initial CCA





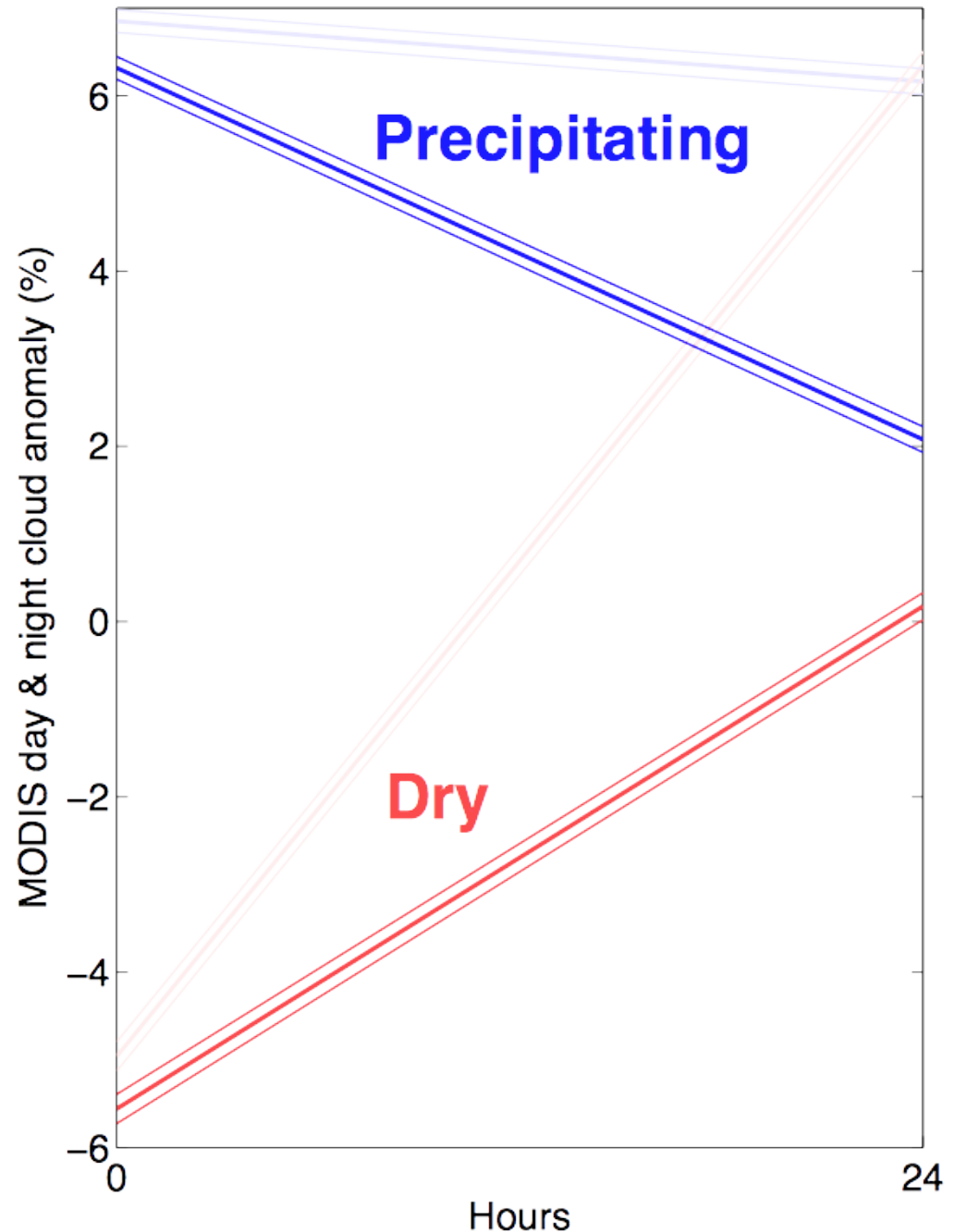
# $\Delta CCA$ Bounded by $CCA(0)$



- An initial anomaly of -100% can only increase
- An initial anomaly of +100% can only decrease
- Blue line: If anomalies persisted perfectly
- Black line: If  $\Delta CCA$  were random
- $\Delta CCA$  is in part a function of  $CCA(0)$

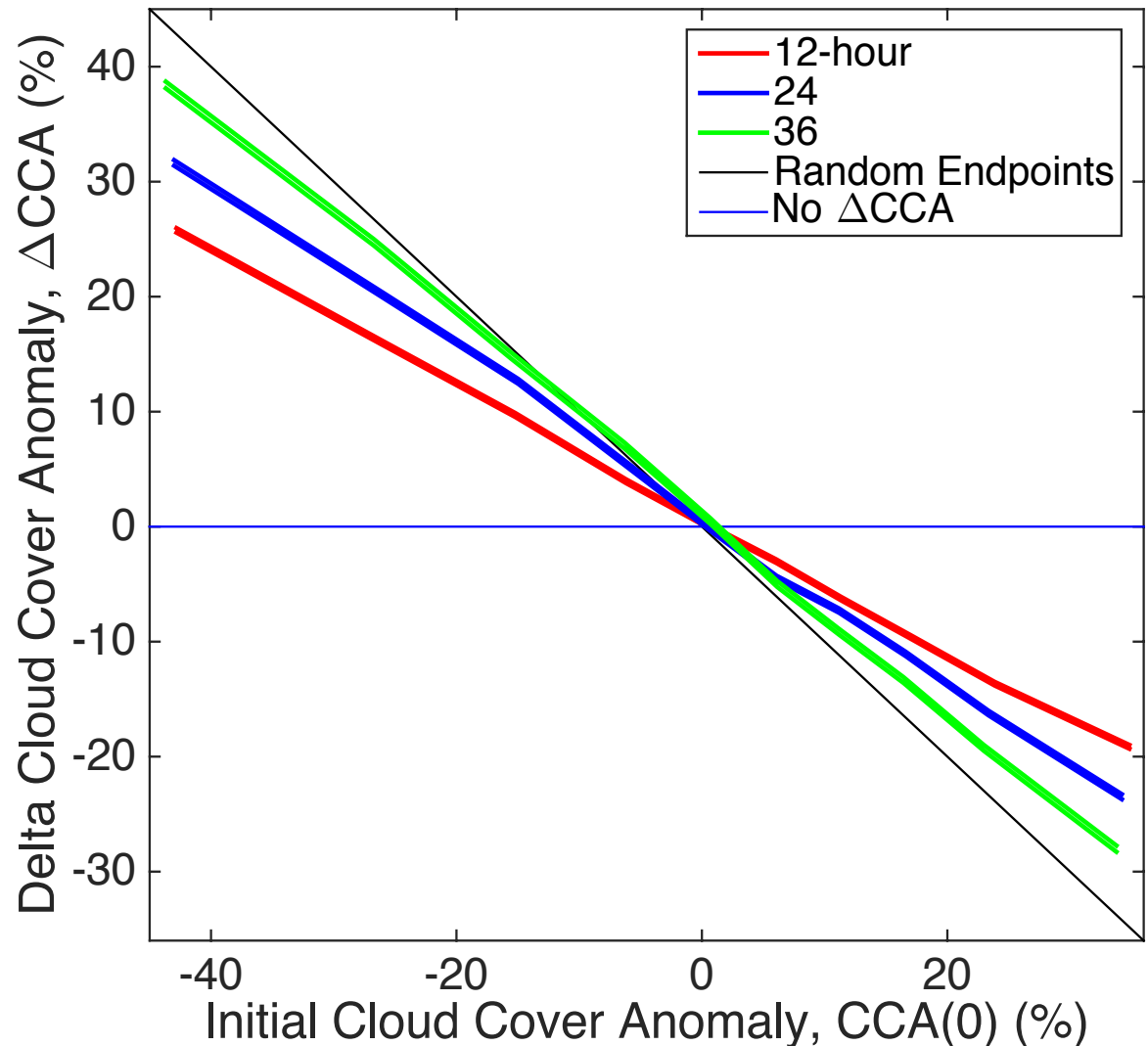
# Bias from Differing Initial Distributions

- Average initial CCA is different for dry vs. precipitating trajectories
  - Increasing  $\Delta\text{CCA}$  for dry trajectories is partially a function of the below 0 initial anomaly
  - Decreasing  $\Delta\text{CCA}$  for precipitating trajectories is partially a function of the above 0 initial anomaly
- So directly comparing  $\Delta\text{CCAs}$  is misleading



# $\Delta\text{CCA}$ as a function of $\text{CCA}(0)$

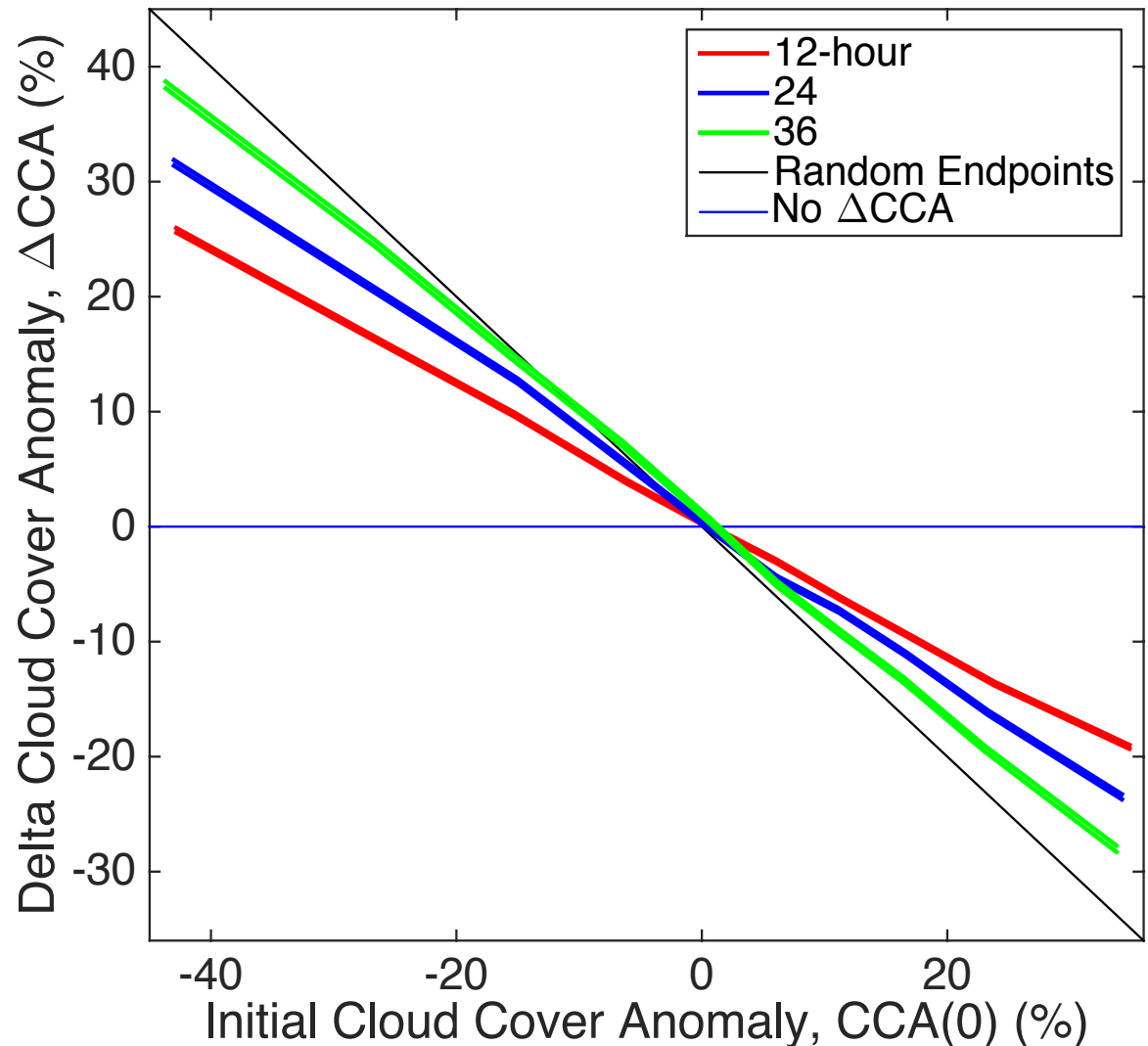
- $\Delta\text{CCA}(\text{CCA}(0))$  for 12-, 24-, and 36-hour trajectories
- Linear relationships, with the slope steepening over time
- $\Delta\text{CCA}$  is (in part) a red noise process
- On average, CCA's evolve to compensate the initial anomaly



# Residual $\Delta$ Cloud Cover Anomaly

$$\overline{\Delta CCA} = \overline{\Delta CCA(CCA_0, time)} + \overline{\Delta CCA(meteorology)}$$

- $\Delta CCA$  is a function of  $CCA(0)$ , time, and meteorology
- This plot shows the mean  $\Delta CCA$  that is a function of initial  $CCA$  and time
- Remove that portion of  $\Delta CCA$  to compute a 'residual'  $\Delta CCA$ , independent of  $CCA(0)$





# Calculating the residual $\Delta CCA$

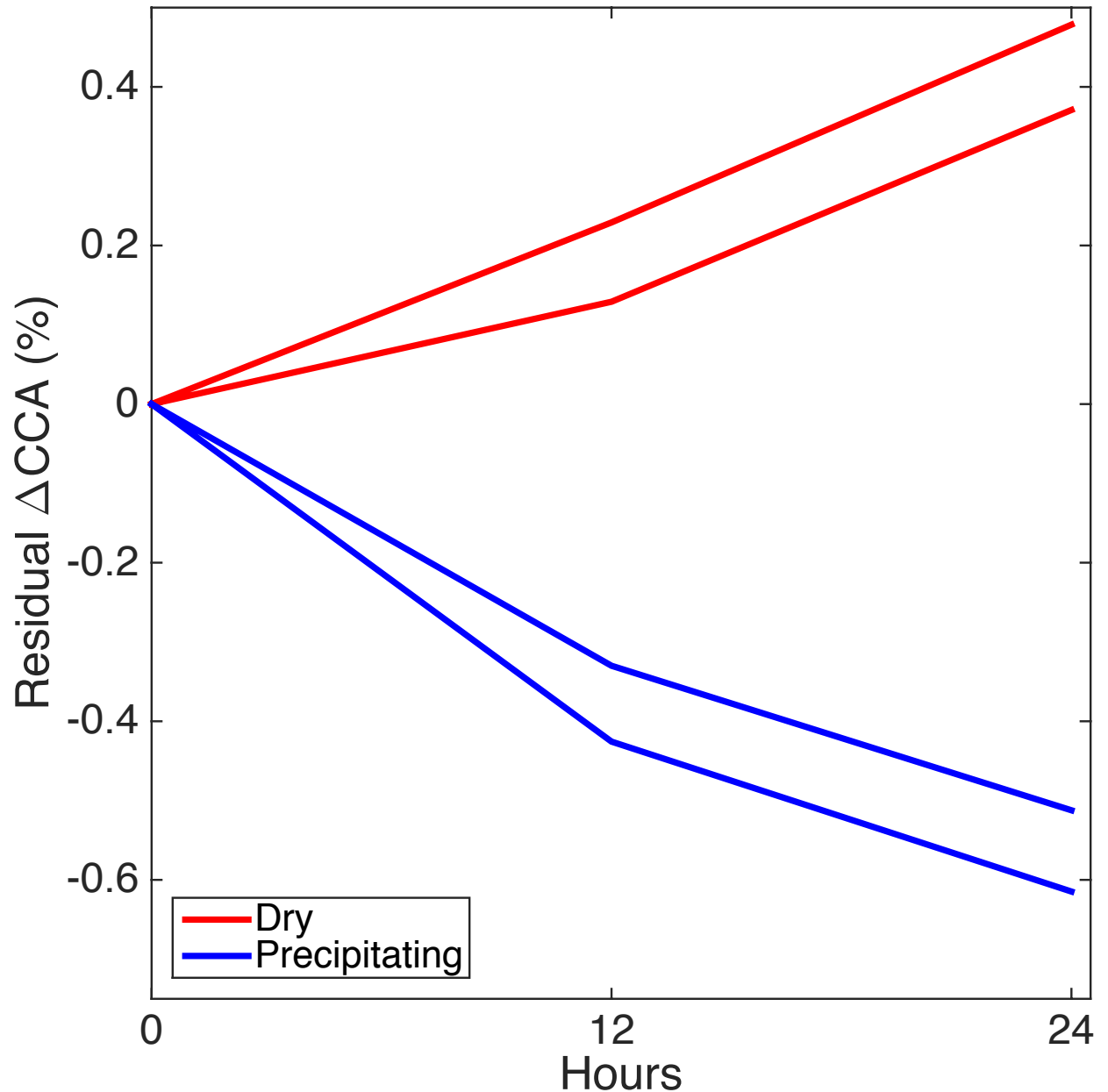
- eg: A trajectory begins with a CCA of +10 % and decreases by 20% in 12 hours:
  - Using the previous figure, an initial anomaly of +10% shows (on average) a decline of -5% in 12 hours

$$\begin{array}{ccccccc} \textit{Residual } \Delta CCA(12) & = & \Delta CCA(\textit{observed}) & - & \overline{\Delta CCA(+10\%, 12 \textit{hrs})} \\ -15\% & & (-20\%) & & (-5\%) \end{array}$$

- Look for variables that significantly alter the residual  $\Delta CCA$ , which is only a function of meteorology, with no initial distribution bias

# Residual $\Delta$ CCA and Precipitation

- Precipitation still appears to have an effect, though smaller
  - Difference of only 1 or 1.5%
  - Significant at 12 and 24 hours

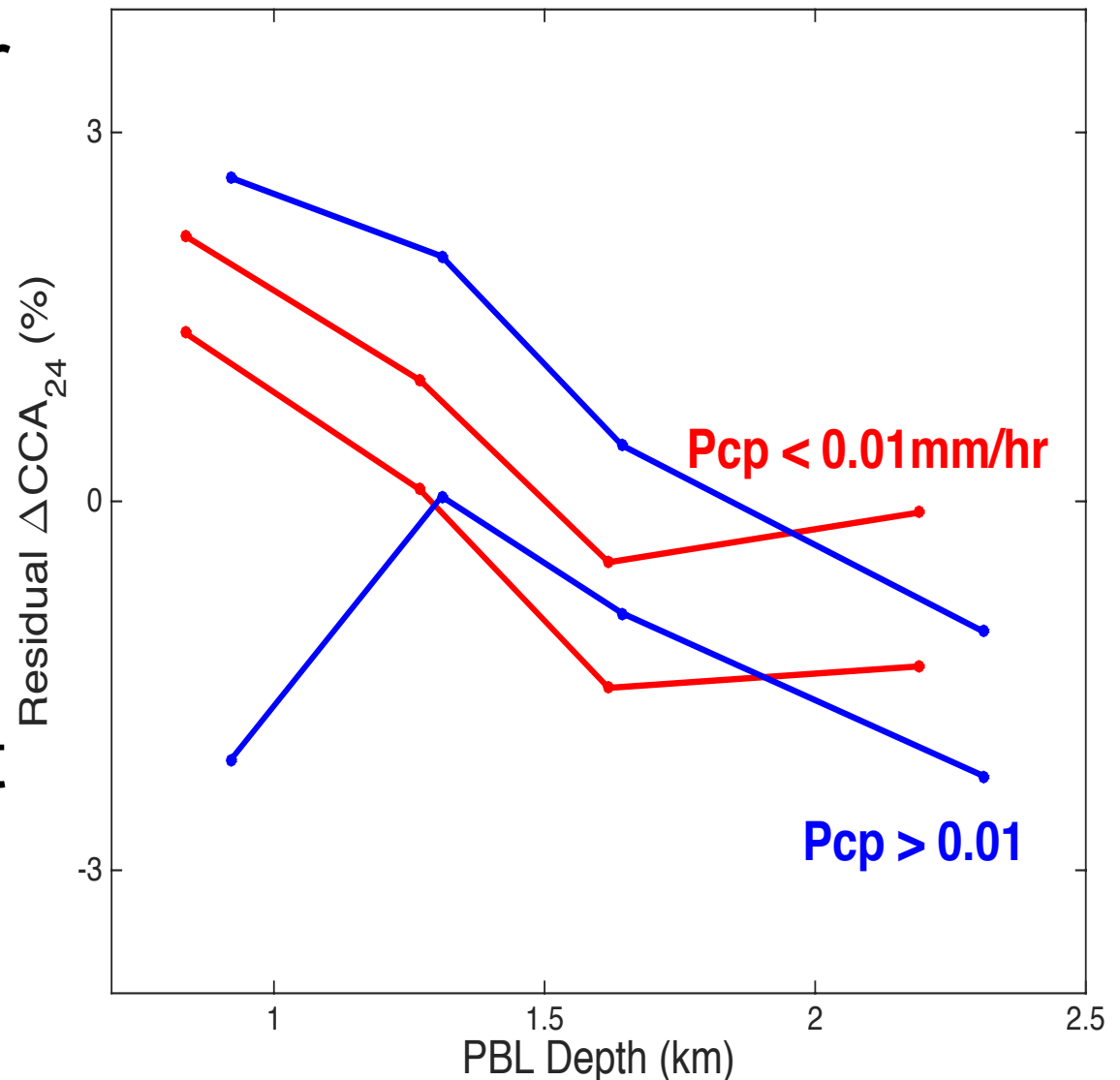


# Factors aside from precipitation

- Precipitation is correlated with other variables, which, in turn, are correlated with each other eg...
  - Precipitation tends to occur in deeper boundary layers ( $r = 0.35$ ), and is slightly correlated with lower-tropospheric stability ( $\theta_{700} - \theta_{1000}$ ,  $r = -0.12$ )
    - Derived from CloudSat Auxiliary reanalysis from ECMWF
  - Lower tropospheric stability values correlate negatively with boundary layer depth ( $r = -0.45$ )
- What is actually producing this result? Is precipitation the driving variable, or is it something correlated with precipitation?

# Binning Residual $\Delta\text{CCA}$ for constant boundary layer depths

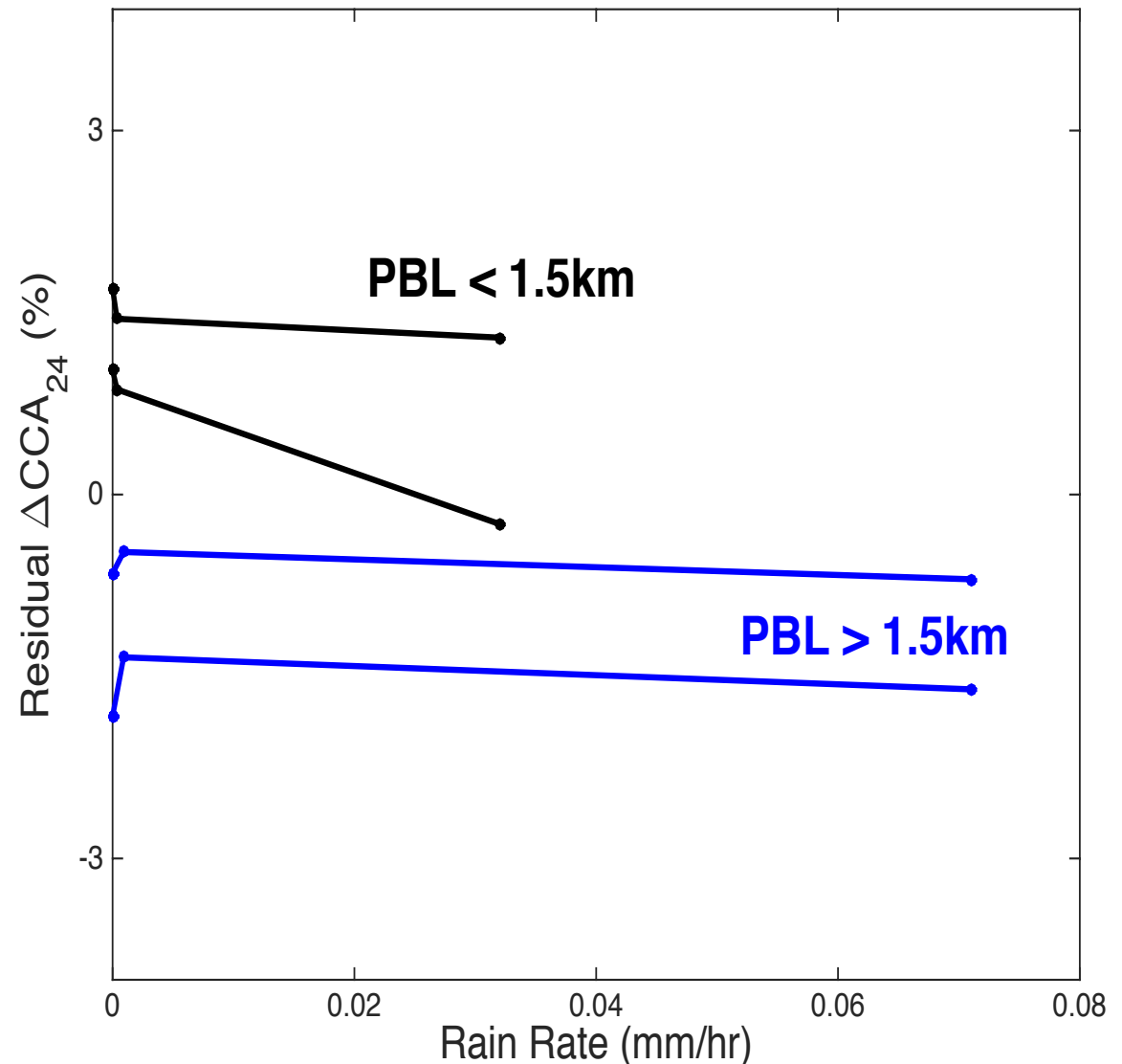
- Hold boundary layer depth constant in separate bins for precipitating and dry trajectories
  - Bins with equal N
- See if precipitation still has a significant affect
- Appears not to





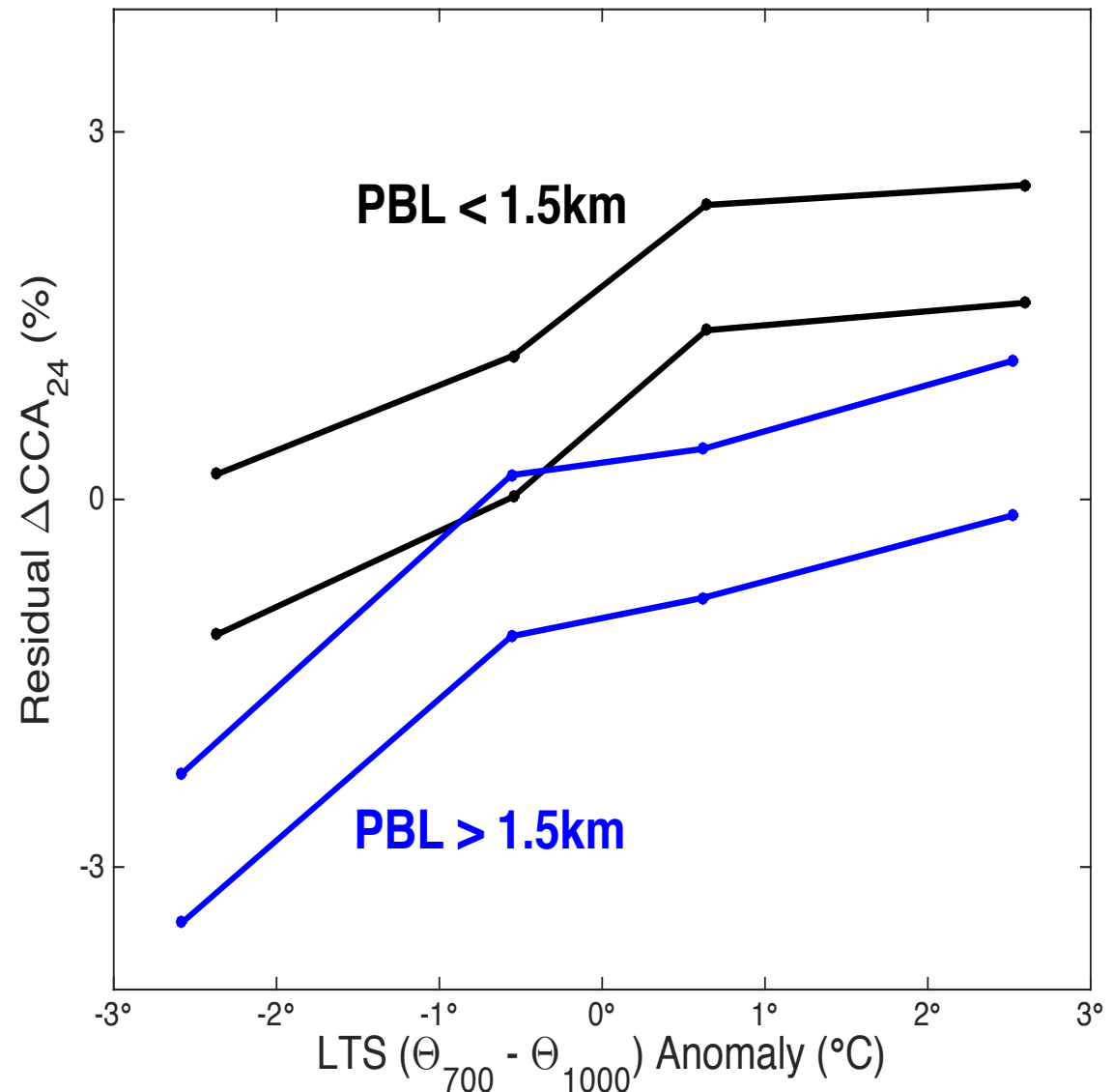
# Binning Residual $\Delta\text{CCA}$ for constant precipitation frequency (inverse)

- Hold precipitation frequency constant, see if shallow and deep boundary layers evolve differently
- They do
  - Shallow boundary layers persist
  - Deep boundary layers tend to break up



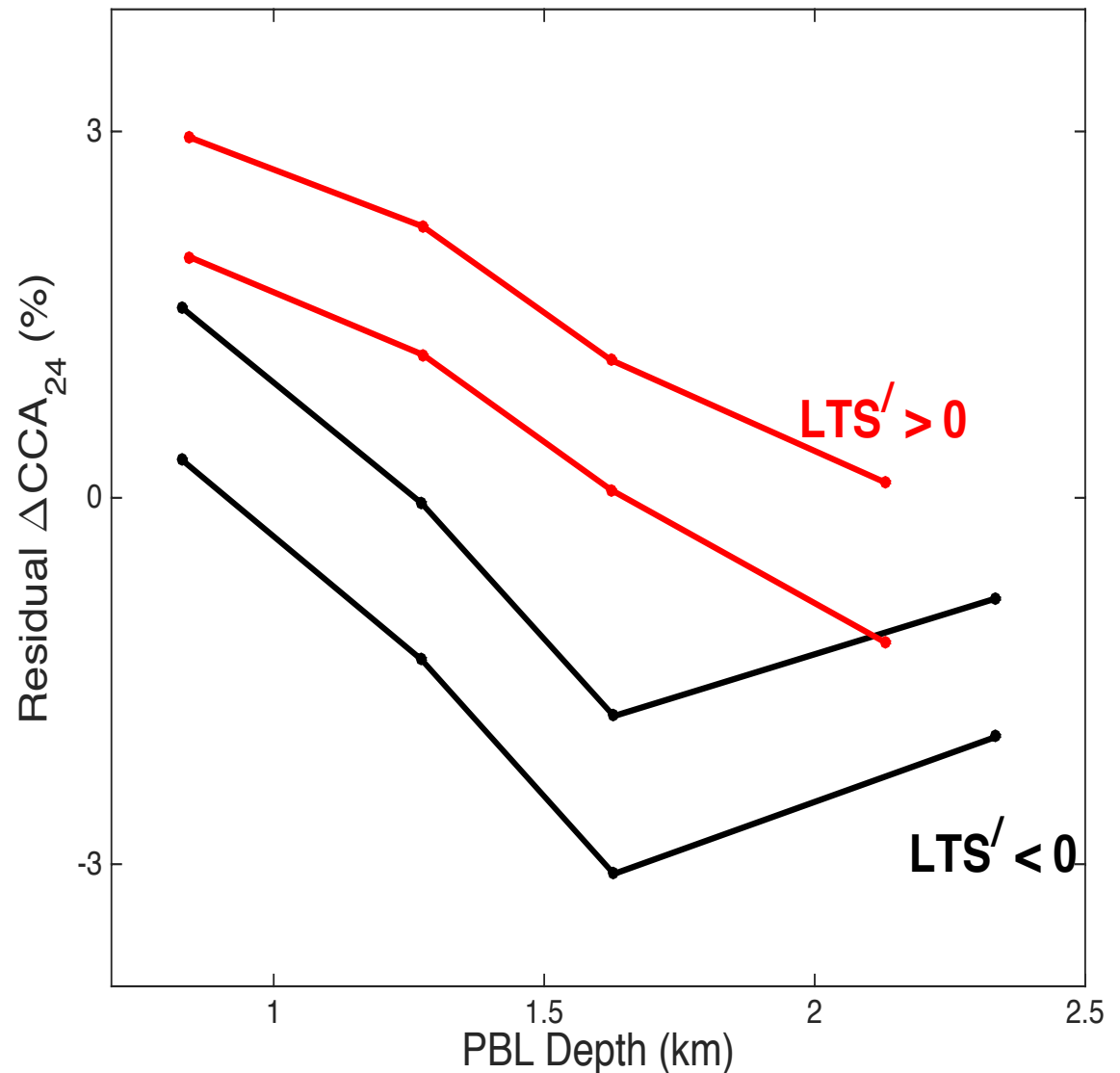
# Binning Residual $\Delta CCA$ for constant LTS ( $\theta_{700} - \theta_{1000}$ ) Anomalies

- Boundary layer depth is well correlated with LTS
- Deep boundary layers break up more readily for bins of constant LTS
- Slopes suggest that LTS may also have an influence



# Binning Residual $\Delta CCA$ for constant boundary layer depths (inverse)

- Invert the previous figure to see if LTS has an effect for bins of constant boundary depth
- Appears to have a significant effect
  - High LTS (strong inversion) allows clouds to persist
  - Low LTS associated with breakup



# Results for binning Residual $\Delta CCA$

- Precipitation does not appear to be a significant driver of cloud breakup
- Instead LTS and boundary layer depth both seem to matter more
- Strong inversions tend to maintain cloud cover independent of boundary layer depth
- Deep boundary layers tend to break up more readily independent of inversion strength
- We are incorporating more satellite products into this analysis, esp. LWP/Aerosol/Radiation products